HISTORICAL SHORELINE CHANGE OF THAP SAKAE COAST, PRACHUAP KHIRI KAN, THAILAND

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***Abstract*—**Coastal erosion is a critical problem in Thailand significantly affecting the coastal development and economy of the country. This paper presents the situation of shoreline change along the Thap Sakae coast, which is one of the highest potential areas for Thailand's coastal development. To evaluate the coastal erosion situation of the study area, ten shoreline positions were extracted from the aerial photographs and satellite images taken between 1966 and 2017 using the Geographic Information System (ArcGIS). The rates of shoreline change were analyzed by the Digital Shoreline Analysis System (DSAS). Additionally, field surveys was carried out in 2018 to observe the current coastal environment. Based on the results from shoreline analyzes, the long-term (1966-2003) and short-term (2003-2017) average rates of shoreline change along the Thap Sakae coast were -0.14 and 0.3 m/y, respectively. As the average rate of shoreline change was less than ±1 m/y, the Thap Sakae coast seemed to be a stable coastal area. However, local coastal erosion was found during the past 15 years due to land development mainly for tourism purpose. Coastal protection structures were found in many locations along the study area. Those coastal developments and coastal protection measures have likely been driving the negative effects on their adjacent shoreline. As Thap Sakae coast has a high economic value, an erosion rate with a small degree can cause significant damages to the local and regional economy.

Keywords—coastal erosion, sandy beach, human activities, coastal protection

I. INTRODUCTION

A coast is a place that land interacts with the sea, and it is one of the most dynamic earth features. There are several natural factors such as wind, wave, tide, and nearshore current affecting shape of a coastline by either moving it landward or seaward [1]. Human activities are also the major causes of shoreline change, for example, coastal developments for tourism, fishery, shipping, transportation, and energy production, and they can significantly alter coastal processes and shoreline movement patterns [2][3][4]. Due to increasing population growth in modern society, many cities and infrastructures have been developed along the coasts worldwide [5][6]. Two-third of the world's megacities are situated on the coastal areas, however, they are vulnerable to shoreline retreat and natural hazards [4]. A construction of the coastal or marine structure typically disturbs the long-term equilibrium of the shoreline resulting in shoreline migration [7][8][9]. As an investment in coastal zone is normally immense, the study of historical shoreline changes including the observation of the existing coastal structures along the coast is necessary for a coastal project planning and development. Meanwhile, post-construction monitoring is a crucial process in order to evaluate the function and effectiveness of the structures and/or the project [4].

In Thailand, Prachuap Khiri Khan Coast situated on the west side of the Gulf of Thailand has about 250 km long [10]. The coast comprises of several different coastal features such as rocky coast, sandy coast, cliff, lagoon, mangrove forest, and tidal flat, which have been continuously developed since the past. However, the Department of Marine and Coastal Resources, Thailand, reported that a critical coastal erosion with the rate of more than -5 m/y was recently found in some locations such as Khlong Wan, and Ban Thung Pradu villages [10][11].

The aim of this paper is to document the historical shoreline changes along the Thap Sakae coastline (Fig. 1), a part of the Prachuap Khiri Khan Coast, which is a potential site for several coastal development projects. The paper summarized the long- and short-term shoreline change rates including the current situation of shoreline change along the Thap Sakae coast. The information provided a more comprehensive view of the coastal change in this area and key references that can be used for coastal planning and management in a regional context.

II. STUDY AREA

The Thap Sakae coast is located in Prachuap Khiri Khan Province in the southern part of Thailand, bounded by 11° 22' to 11° 45' N and 99° 34' to 99° 47' 00" E. The study area covered about 50 km of the sandy coastline extending from Khlong Wan Mountain (the meaning of "Khlong" is channel) to Thong Chai Mountain as shown in Fig. 1. The coastline is characterized by sand, gravel, silt, shell fragment, and organic matter [12].

The climate of the study area is dominated by two major monsoons. The Southwest monsoon generates southwestward wind during May to September causing moderate wave with an average wave height of about 0.1-0.5 m. The Northeast monsoon, which starts from December through March, brings northeastwardly strong wind of 4-8 knots and intense wave of 0.5-2.0 m high [13] [14].

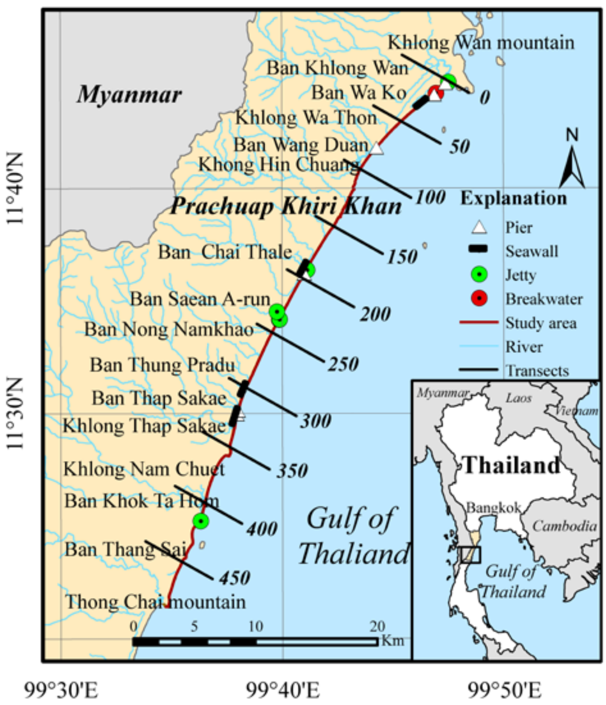

Fig. 1. Location of Thap Sakae coast.

III. MATERIALS AND METHODS

A. *Compilation of historical shoreline*

Historical shoreline positions along the Thap Sakae coast were derived from aerial photographs and satellite imagery taken in 1966, 1976, 1994, 1997, 2002, 2003, 2013, 2014, 2015, and 2017. The TIF images of scanned aerial photographs and satellite data were rectified using the Geographic Information System (ArcGIS) software version 10.4 by placing at least 8 well-spaced ground control points to remove distortions from aerial photographs with root mean square errors (RMSE) of less than 1.0 m. All images were projected to Universal Transverse Mercator with reference to the World Geodetic System 1983 (WGS1983), and then shorelines were digitized. Even though the High Water Level (HWL) has been typically used as the shoreline proxy for more than 150 years because it could be visually detected in the field [15][16][17], different proxies can be used to define the shoreline positions depending on coastal location, data sources and scientific preference [15]. In this study, the vegetation line, boundary of coastal structure, and cliff base were used for representing shoreline positions. Shorelines from all sources were merged to produce a single shoreline shapefile for calculating shoreline change rates.

The rates of shoreline changes in the study area were evaluated in ArcGIS with the Digital Shoreline Analysis System (DSAS) version 4.3 [18] developed by United States Geological Survey in cooperation with TPMC Environment Service [15][18]. In order to analyze the shoreline change using DSAS, baselines were constructed parallel to the general trend of the Thap Sakae shorelines. The 482 transects were generated perpendicular to the baseline with the spacing of 100 m (Fig. 1). The long-term rates of shoreline change (between 1966 and 2003) were calculated at each transect using linear regression (LRR) method, which is the most statistically robust quantitative method when the number of shorelines is limited [16][18]. Meanwhile, the endpoint rate method (EPR) is used to calculate the short-term shoreline change rates which are calculated with 90 percent of the confident interval to compare the 2003 and 2017 (most recent) shoreline positions.

The movement of shoreline was also calculated by DSAS. Statistic method called Net Shoreline Movement (NSM) was used to calculate the distance of net shoreline change. This method measures the distance of shoreline from oldest to youngest.

B. *Field observation*

As Thap Sakae coast composes of a wide range of coastal landforms and has been developed during the past decades. A field survey was carried out on 5^{th} -7^{th} June 2018 to observe the existing coastal characteristics including human activities along the Thap Sakae coast. Eight survey locations, Ban Khlong Wan (transect 7), Ban Wa Ko (transect 28), Ban Wang Duan (transect 76), Ban Chai Thale (transect 192), Ban Sang A-run (transect 238), Ban Thung Pradu (transect 303), Ban Thapsakae (transect 321), and Ban Khok Ta Hom (transect 414), where the major development can be recognized from the remote sensing data, are illustrated in Fig. 1.

IV. RESULTS AND DISCUSSION

Regarding the shoreline change analyzes in this study, long-term and short-term shoreline change rates along the Thap Sakae coast are shown in Fig. 2a and Fig. 2b, respectively. A positive value of the shoreline change rates denotes the distance of shoreline moving seaward per year (shoreline accretion rate). Meanwhile, the negative value represents the distance of shoreline migrating landward per year (shoreline retreat rate). The substantial erosion/accretion trends including human-induced change within the Thap Sakae coastal system are discussed below.

A. *Long-term shoreline change along the Thap Sakae coast*

Based on the results from long-term shoreline change analysis, approximately 65 percent of the Thap Sakae coastline was eroding. The net long-term shoreline change rate averaged over 482 transects was -0.14 m/y with an erosional trend. The recession of the shoreline was mainly found between Khlong Hin Chuang and Thong Chai mountain (transect 27-428) (Fig. 2a) with the net land loss of 0.42 km^2. The highest erosion rate of -1.3 m/y was measured on the south of Khlong Thap Sakae inlet (Fig. 2a). Long-term accretion occurred along the remaining 25 percent of the Tap Sakae coastline. The significant accretional trend was mainly found at Ban Sang A-run and Ban Thang Sai (transects 238-460). However, the maximum long-term accretion rate of 2 m/y was measured at the inlet of Khlong Ang Thong (Fig. 2a). The net long-term land accretion was about 0.17 km^2.

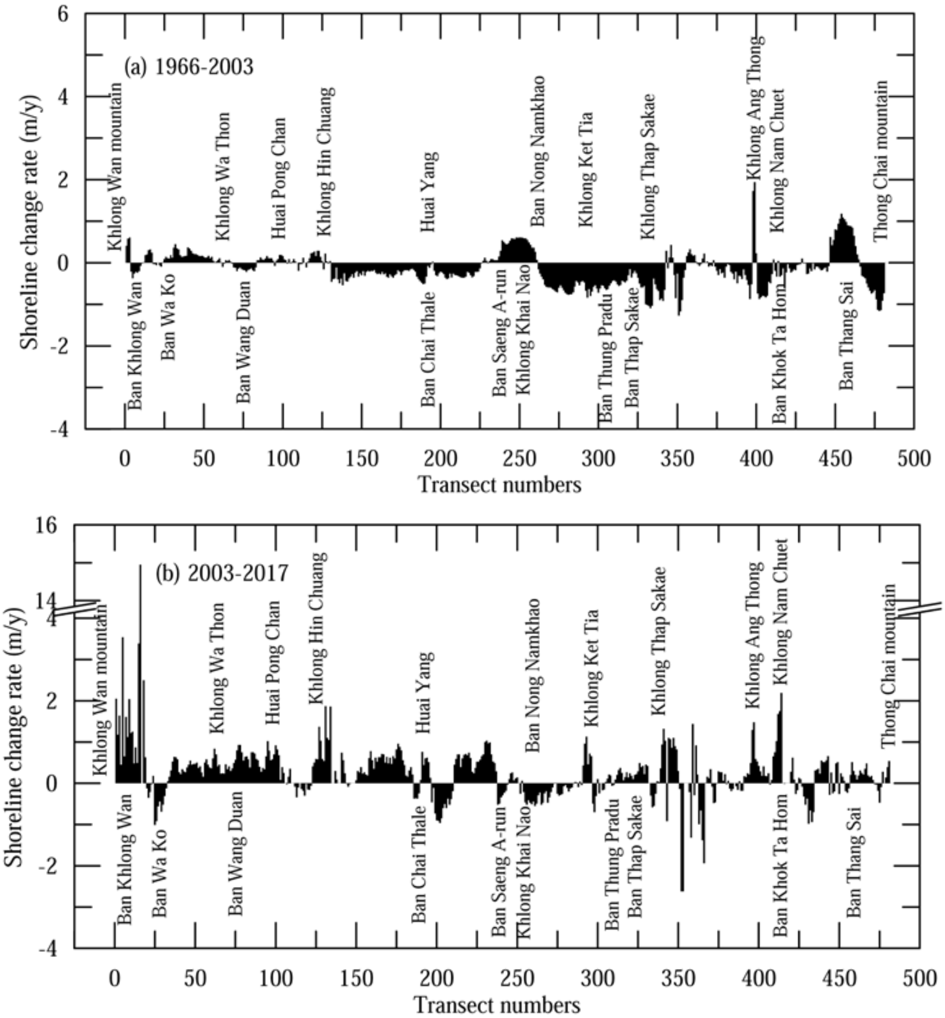

Fig. 2. Shoreline change rates along the Thap Sakae coast (a) Long-term change rates during 1966-2003 (b) Short-term change rates during 2003-2017.

B. Short-term shoreline change along the Thap Sakae coast

Results from short-term shoreline change analysis revealed that the average short-term shoreline change rate throughout the Thap Sakae shoreline during the past fourteen years was 0.3 m/y. Along the 70 percent of the total coastline had a short-term accretional trend with the average rate of 0.56 m/y. The maximum shoreline accretion rate of 15 m/y occurred at the upcoast of Ban Khlong Wan (Fig. 1) fishery pier (Pier 2 in Fig. 3) constructed in 2005. The total land accretion was 0.24 km^2 during the period 2003-2017. The shoreline change trends of more than half of the eroded areas have shifted from long-term erosional to short-term accretional trends. About one-third of the Thap Sakae coastline was still experiencing erosion during the period 2003-2017. However, the average rate of short-term shoreline retreat in this area was less than -1 m/y. The highest shoreline recession rate of -2.6 m/y taking place at 2.3 km from the Khlong Thap Sakae (transect 353) southward seemly related to natural changes in beach features and riverine system. Total land loss between 2003 and 2017 was 0.05 km^2. Decreasing of the shoreline erosion rate seemed to relate with coastal development and protections during the recent year.

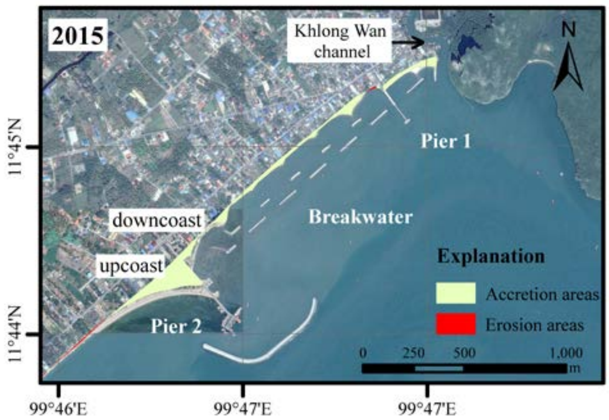

Fig. 3. Shoreline change during 2003-2015 at Ban Khlong Wan (transects 1-22).

C. Comparison between long- and short-term shoreline changes.

Based on satellite imagery and field survey data, many coastal projects have been developed along the Thap Sakae coasts as shown in Fig. 1, and the shoreline has responded to those coastal developments in different degrees.

For example, Ban Khlong Wan coast located between transects 1 and 22 had a significant shoreline erosion up to -20 m during the period 1966-1976. Pier 1 (Fig. 3) was built in 1989 for fishery purposes. The pier has trapped sediment from the Khlong Wan, which transported southwardly, resulting in sediment deposition along the previously eroded coast. In 2005, a new fishery pier (Pier 2 in Fig. 3) was constructed causing a significant sand deposition on the southern side of the new pier (Fig. 3) with the maximum distance of 220 m. Series of the offshore breakwater was built as a part of new fishery project to mitigate sediment starvation on the northern side of the pier (Fig. 3). Even though Pier 2 has caused land accretion on the upcoast of the structure, the coast along Ban Wa Ko located on the south of the Pier 2 has experienced a significant shoreline retreat (Fig. 4) response to the changes in coastal processes due to the Pier 2. Between Khlong Wa Ko and Khlong Hin Chuang (transects 35-135), the rate of accretion obviously increased recently resulting in increasing of shoreline accretion of about 1.5 times (Fig. 2). As this section is located between two major channels, the significant shoreline advance in this region seemed to reflect the increase of sediment supply from the Khlong Wa Thon and/or Khlong Hin Chuang channels.

Along Ban Chai Thale coast (between transects 135 and 215), the rate of shoreline change in this section has shifted from insignificant erosional rate of less than -1 m/y to accretion rate of 1 m/y after the constructions of two jetties at the Huai Kok Ma and Rong Nong Kok Channel mouths in 2005 and 2008, respectively. However, the jetties at Rong Nong Kok Channel mouths caused erosion along the Ban Saeng A-run coast due to the deficit in sediment transporting southward. Between Ban Thung Pradu and Ban Thap Sakae (transects 303 and 321), where the long-term shoreline retreat rate was about -1 m/y, the shoreline has shifted seaward during the past 14 years as a result of land reclamation and coastal protection using seawalls.

The dramatic shifts in erosional long-term trend to depositional short-term trends were found near the coast adjacent to the major channel mouths such as the Khlong Thap Sakae (transect 331), Khlong Ang Thong (transect 399), and Khlong Nam Chuet (transect 413). The maximum short-term erosion rate occurred at a port (transect 353) operated between 1997 and 2007. Since the port has been removed in 2008, the shoreline was readjusting to reach its new equilibrium.

D. Historical of shoreline movement and existing coastal environment along the Thap Sakae coast.

Evolution of the shoreline along the study area compared to the shoreline in 1966 is illustrated in Fig 4. Between 1966 and 1976, most coastal areas had experienced shoreline erosion probably related to three tropical depressions directly hitting Prachuap Khiri Khan coast in 1975 [19]. After that shoreline change pattern along the Thap Sakae coast was mostly steady. The maximum distance of shoreline accretion was 200 m occurred at the south of pier at Ban Khlong Wan (Pier 2 in Fig. 3). While the highest shoreline recession was 50 m was found at the south of Khlong Thap Sakae (transect 351). Land accretion mainly took place at river mouths, such as Khlong Wa Thon (transect 62), Khlong Khai Nao (transect 253), Khlong Thap Sakae (transect 331) and Khlong Nam Chuet (transect 413)(Fig. 4), which are the major sources of sediment supply to the coast. In contrast, land losses were found at Ban Nong Nam Khao (transect 262), the south of Khlong Thap Sakae (transect 351) and the north of Thong Chai mountain (transect 475).

From 1966 to 1976, the shoreline near the mouth of Khlong Wan retreated with the distance of about 20 m. After the construction of concrete pier (Pier 1 in Fig. 3) in 1996, it was found that shoreline between the river mouth and Pier 1 migrated seaward of about 15 m in 2002. As a result of the construction of a new fishery pier (Pier 2) at Ban Khlong Wan in 2005, longshore sediment transported northward were trapped at the upcoast of Pier 2. Therefore, seawalls and series of offshore breakwater were constructed at downcoast of the Pier 2 in order to reduce the beach erosion affected by the pier. Based on a field survey in 2018, however, failure of those coastal protections was found on the southern coast of Pier 1 as shown in Fig. 5. Ban Wa Ko coast located on the south of Pier 2 has also faced shoreline retreat because Pier 2 has trapped the longshore sediment transporting southward. Consequently, the downcoast experienced more than 15 m of shoreline retreat. Field surveys data indicated that private seawalls constructed by landowner have successfully protected the horizon changes (Fig. 6), but the vertical erosion of the beach occurred in front of those seawalls as depicted in Fig. 6.

Along 20 km coastline from Khong Wa Ko to the south (between transects 31 and 225), the pattern of shoreline migration slightly changed except the coastlines adjacent to the river mouths (Khlong Wa Thon, Huai Pong Chan, and Khlong Hin Chuang), which the shore mostly grew seawards due to sediment supply from the rivers. However, the shoreline recession was found at both upcoast and downcoast of Huai Yang river mouth (transect 192). Although, several coastal structures such as seawalls and jetties were applied to stabilize the coastline, up to -20 m of shoreline retreat was observed along the coast. It indicated that the sediment supplied from Huai Yang Channel was significantly less than longshore sediment transport in this area.

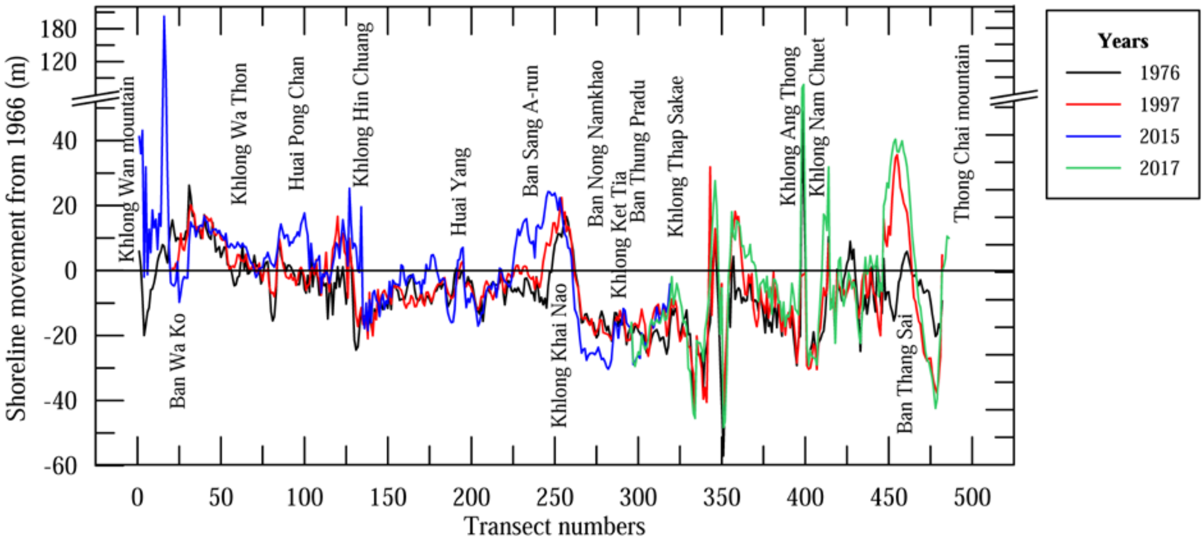

Fig. 4. Historical shoreline movement along the Thap Sakae coast during the period 1966-2017.

Fig. 5. Failure of shoreline protection at Ban Khlong Wan between transect 3 and 5.

Fig. 6. Beach erosion along Ban Wa Ko.

Along 3.5 km coastline between Rong Nong Kok (Ban Sang A-run) and Khlong Khai Nao channels (transects 225 - 260), the shoreline near Khong Khai Nao inlet has migrated seaward of about 20 m during the period 1966-2015 reflecting the significant amount of sediment supply from Khlong Kai Nao. Results from shoreline analysis indicated that the net sediment transported northward and sank at the inlet of Rong Nong Kok channel to prevent sedimentation in the navigation channel in 2007. A pair of jetties with 40 and 50 m long was constructed at the southern and northern sides of the river mouth, respectively. Unfortunately, the jetty functioned as intended only several years because it was too short for trapping the large amount of sediment transporting to the south. The jetty improvement was done in 2015. The length of the south- and north- jetty structures were extended to 60 and 110 m, respectively .

The 1.5 km coastline from Ban Nong Nam Khao to Ban Thung Pradu (transects 260 to 310) has experienced shoreline retreat of more than -20 m between 1966 and 1976. Then the coast seemed to be stable during the period 1976-1997 (21 years). However, the abrupt shoreline retreat of more than 10 m occurred between 1997 and 2017 (Fig. 2 (b)). Moreover, the beach in this area was narrow with the beach width of about 10 to 20 m. Even though the rate of shoreline change in this area may be low (less than -1 m/y) compared to other regions of the country, it has caused severe damages to local communities living along the coast as shown in Fig. 7. Figure 8 presents the construction of coastal protection structure (seawall) to mitigate the coastal land loss in this area.

Fig. 7. Beach erosion and property damages along Ban Thung Pradu.

From Ban Thap Sakae to Ban Thang Sai (transects 310-455), most of the 14.5 km long coastline in this section has undergone shoreline recession. The coast was severely eroded more than -40 m in some locations during the period 1966-1997. Concrete seawall with 500 m long was built to stabilize the eroding shoreline. Since 1976, the northern portion of the coast has been more or less stable. At the southmost of the study area, Thong Chai Mountain was situated. As it functioned as a headland of the study area, no significant shoreline change has been observed during the past five decades.

Fig. 8. The seawall was under construction along Ban Thung Pradu.

V. CONCLUSION

Historical shoreline analysis over the past five decades from this study indicated that 65 percent of the Thap Sakae coastline, Prachuap Khirikhan Province, has experienced coastal erosion with the long-term land losses and land accretion of 0.42 km^2 and 0.17 km^2, respectively. Although the average long-term rate of shoreline retreat was generally low (-0.37 m/y) , about 30 percent of the coastline was still eroding during the past 14 years with the short-term erosion rate of about -1 m/y. The highest rates of shoreline recession (-2.62 m/y) were found near a headland (2.5 km from Khlong Thap Sakae toward the south) relating to natural interaction processes among beach features, riverine system, and local wave climate. The decrease in eroded coastline was related to coastal protection measures applied along the coast recently.

The long-term shoreline accretion was found in several places near the river mouths with an average rate of generally less than 1 m/y. As many coastal developments and coastal stabilization projects have been developed along the Thap Sakae coast during the past 14 years, more than 50 percent of the areas with the erosional trend has shifted to accretional trend. Up to the present, land accretion along the Thap Sakae coast has increased to 0.24 km^2. The maximum shoreline advance of 200 m was found near the new Ban Khlong Wan fishery pier.

The rates of shoreline change along Thap Sakae coast seem to be not critical compared to that found in other coasts of Thailand such as the Chao Phraya Delta coast, which the erosion rate was more than -25 m/y. However, based on field observation, severe damages on private properties were found in many locations. As the Thap Sakae coastline is characterized by narrow sandy beaches, such a low rate of shoreline change can cause significant effects on coastal development in this area.

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